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FOOD SUPPLY AS A FACTOR IN SEASONAL CHANGES OF METABOLISM IN BALTIC COD

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The main processes in the life of cod - growth and reproduction - are characterized by a specific system of relations to the environment. The food supply during the autumn feeding migration determines the growth rate of specimens and, to a certain extent, also the size of the spawning stock. During the spring period, the food supply influences the intensity of reproduction processes.

Food supply is one of the very important factors determining the intensity and the direction of metabolism in fish. However, it is very difficult to determine the impact of this factor on the vital functions of fish under natural habitat conditions, because it depends on numerous components (quantity and specific composition of food, its quality and accessibility, etc.). The most rational way of studying the food supply is to determine the effect of its use from the intensity of the reserve substances storage, the intensity of weight gain and linear growth and the maturing of sexual products (3;9). In this connection we have attempted, by means of a combined analysis of the changes in the amount of food in the digestive tract and the dynamics of some morpho-physiological and physiologo-biochemical indexes in

cod, to determine the effect of the changes in food supply on the direction of metabolism during the various periods of the annual cycle.

The growing period

The annual cycle of cod may be divided into several periods - growing, pro-spawning, spawning - however, foraging cod can be seen throughout the entire year, a feature that distinguishes this species from a number of other commercial species of the Baltic Sea. The intensity of feeding and the specific composition of food organisms change with the season (6;8), and this causes changes in the behavior and the distribution pattern of cod. Thus, the highest increase in size of cod occurs during the fall and winter, when the total biomass and the quantity of Mysidacea and large isopods (Mesidothea entomon) are the highest and the herrings and sprats gather in the benthic layers and are easily accessible. At the same time there is an intensification of assimilatory processes: the content of lipids in the liver, proteins in the muscles and fullness of fish increase (Fig. 1).

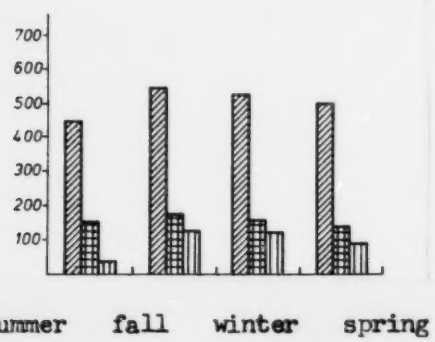

Fig. 1. Seasonal changes in the content of lipids in the liver (I - mg/g), proteins in the muscles (II - mg/g), and in the general indexes of fullness of stomach (III - $0/_{000}$).

It must be pointed out that in the course of preparation for wintering during the fall period, the content of lipids in the muscles of herring and sprat reaches maximum values; in the large isopod - typical representative of the boreal-arctic complex - the storage of fat also is intensified, reaching a maximum during the winter period (Fig. 2). Thus, there is a relation between the intensity of assimilatory processes in the consumer and the nutritional value of food, since an increase in the energy reserve of food, in particular the content of lipids, is accompanied by a more effective utilization of proteins by the organism (10; 12).

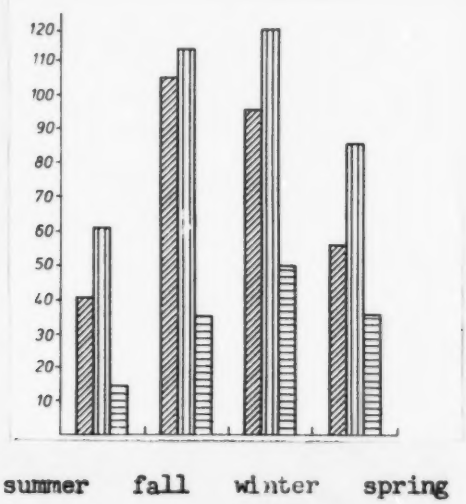

Fig. 2. Seasonal changes in the content of lipids in the organisms on which cod feed: Baltic herring (I), sprat (II), and large isopod (III).

Naturally, the above relationship should be understood only as a general scheme from which there may be deviations during some years depending on changes in the hydrological regime and the closely related changes in the quantity of food organisms, as a result of which cod's food supply may vary considerably.

A comparison of the physiological condition of sexually mature cod specimens in the fall period carried out for a number of years did not always reveal a correspondence between the level of physiological indexes and the amount of food in the digestive tract. Thus, for the period from 1973 to 1977, the lowest amounts of food in the stomach were observed in the fall of 1973 and 1975, and the content of lipids in the liver, the hepatosomatic index and the reserve of of lipids in the organism were the lowest in 1974 and 1975 (Table 1). The considerable increase in the coefficient of variation of the lipid content in the liver during these years is an additional proof that cod's food supply was low, since one of the conditions for triggering an adaptive reaction at the population level is the different quality of the basic ecologo-physiological properties of the specimens that make up that population. /66

Table 1

Fullness and the physiological condition of cod in the growing period (1973-1977)

Indexes	1973	1974	1975	1976	1977
General index of fullness of stomach, $^0/_{000}$	107	129	109	127	130
Composition of food bolus, %:					
Mesidothea entomon	42	63	47	14	38
Mysis sp.	12	2	9	21	11
Pontoporea sp.	7	12	14	28	23
Harmathoe s.	14	13	13	13	3
Fish	24	23	17	24	25
Lipid content in liver, mg/g	559 558	463 409	450 473	524 431	600 587
Lipid content in liver, %	15	20	31	16	17

Lipid reserve in organism,	44.1	25.5	34.8	41.1	40.3
g/kg of trunk weight	23.1	22.6	27.1	23.4	47.3
Hepatosomatic index, %	7.6	5.1	6.6	7.6	7.0
	6.5	5.1	5.6	5.8	7.1
Condition (according to Clark)	0.80	0.82	0.74	0.73	0.84
	0.74	0.81	0.73	0.75	0.85

Note: In this and other tables the upper row of figures corresponds to females, the lower one to males.

The lower share of mysids and fish and a much larger share of large-isopod in the diet of cod in those years, especially in the fall of 1974, is noteworthy. As is generally known, large isopods and mysids are cold-water species of arctic origin, and their distribution is associated with relatively cold water layers. Beginning with 1973, the winters in the Baltic Sea zone have been very warm, the winter of 1974-1975 being the mildest in the past 55 years. Apparently, the warming up had a deteriorating effect on the habitat of the mysids and the large isopods and reduced their biomass in the habitual feeding grounds of cod. In its turn, the reduction in the biomass of mysids prevented the formation of large concentrations of fish of the herring family which, undoubtedly, affected the food supply for cod. When the food supply in the form of fish is reduced, the expenditure of energy for catching the relatively small mysids and large-isopods is insufficiently compensated by the energy generated by their consumption, and this lowers the accumulation of fat in cod (Tab. 2).

Table 2

Changes in the intensity of fat accumulation in cod females (35-50 cm in length) depending on the composition of food

Composition of food, %						
herring	Mesidothea ent.	Mysis sp.	Pontoporeia sp.	Harmothoe s.	Lipid content in liver, mg/g	Lipid reserve in organism, g/kg
8.4	66.6	5.7	8.1	11.2	506±48	38.4
40.8	43.3	4.0	2.0	10.7	587±21	46.1

The periodic changes in the specific composition of cod's food raise the question of physiological value of individual nutritional organisms. In the content of alimentary substances per unit of body weight the large isopod is much inferior to the mysids, all the more to the fish (4). Moreover, as the cod grow, they feed on larger isopods whose nutritional value is lower. All this permits one to conclude that, as far as the adult cod are concerned, the large isopod is to some extent a substitute food.

The intensity of growth is an objective criterion of an adequate food supply for fish. Judging from the deviations of the average body length of cod in a given year from the average of several years, the highest growth was observed in 1976 and 1977, and the lowest in 1974 and 1975 (Tab. 3).

Table 3

Deviations of average body length (cm) of cod in individual years from the average for several years

Years	Age 3	4	5	6
1973	-	+0.3	-0.3	-1.9
	-0.6	+0.2	-0.6	-4.1
1974	-0.5	-1.3	-1.5	-0.8
	+0.2	+0.4	-0.7	-1.5
1975	+0.5	-1.0	-0.7	-2.0
	-1.2	-1.5	-1.9	+1.5
1976	+3.5	+2.0	+2.6	+2.5
	+2.0	+1.7	+0.6	+1.9
1977	+1.0	+1.8	+2.6	+2.5
	-0.7	-0.3	+1.2	+1.3
Average for	33.3	41.9	50.6	60.0
several years	34.0	40.8	50.4	58.2

One may conclude on the basis of the above data that, as far as the food supply during the fall feeding period of cod is concerned, the least favorable years were 1974 and 1975. However, the data on fullness and food composition in themselves are insufficient for an evaluation of food supply during the growing season of cod; such an evaluation requires that physiological parameters also be utilized.

The prospawning and spawning periods

The intensity of cod's feeding does not become lower in winter. What does change is the qualitative composition of food: the share of fish increases considerably (Tab. 4), since as the water temperature in the coastal zones drops, the herrings and sprats move to deeper layers and the cod follow.

Table 4

Composition of cod's food from the frequency of occurrence of organisms in the stomach during the first (1) and the second (2) six-month period

Food composition	1		2	
	Length categories, cm			
	35-40	40 and over	35-40	40 and over
Fish	45	64	29	42
Mesidothea ent.	22	26	56	70
Mysis sp.	27	7	78	80
Other invertebrates	53	32	27	24

As a rule, moreover, cod, which at this time stays at considerable depths, has a high content of lipids in the liver and of proteins in the muscles in spite of the fact that it feeds less intensively (Tab. 5).

Table 5

Physiological condition and intensity of feeding in the females of cod of the same age caught at various depths (January, 1976)

Indexes	Depth, m	
	45-50	70-80
Lipid content in liver, mg/g	454±25	457±20
Reserve of lipids in organism, g/kg	30.3	43.6
Protein content in muscles, mg/g	134±7	144±10
General index of stomatic fullness, $^0/_{000}$	141	67

In winter, the intensity of linear growth in sexually mature fish is lower, and it is possible to find specimens within one generation with initiated generative processes; usually, these specimens have large linear dimensions, large weight and present a number of distinctions in the level of physiological indexes (Tab. 6).

During spawning, the females lose with the eggs about 30% of their weight, consequently, to assure oogenesis a great expenditure of energy and the presence of a corresponding reserve of plastic and energy-producing substances are needed. Therefore, the females continue to feed intensively up to the transition to the fifth stage of maturity (Tab. 7). The intensity of feeding in the males drops much earlier because of smaller energy expenditure for gametogenesis and an early departure to the spawning grounds. /67

Table 6

Physiological indexes in cod females of the same age with initiated (I) and uninitiated (II) oogenesis

Group of fish	Fatness (after Clark)	Hepato-somatic index, %	Lipid content in liver, mg/g	Lipid reserve in organism, g/kg	Protein content in muscles, mg/g	Gonado-somatic index, %	Energy reserve, large calorie	Ovary content of RNA mg%P	Ovary content of DNA mg%P
I	0.80	6.8	549	45.1	146	2.8	19.6	967	46
II	0.82	6.7	464	33.2	135	2.0	9.3	1807	48

Table 7

Fullness of cod depending on sex and the maturity stage of gonads

Indexes	Females Maturity stages			Males		
	II	III and IV	V	II	III and IV	V
General index of stomatic fullness, $0/_{000}$	123	111	53	101	76	53
Individual index of stomatic fullness:						
Mysis sp.	11	8	1	12	6	1
Mesidothea entomon	23	22	1	22	16	3
Pontoporeia sp.	4	4	-	4	3	-
Harmathoe s.	8	5	9	10	7	7
herring	37	36	25	24	22	26
sprat	32	30	15	25	20	16
other fish	6	5	2	3	1	1

To these differences in generative processes in the males and females there correspond differences in fullness, the composition of food and in behavior: the females' fullness is 1.5 times higher, the fish diet makes up 70% of the ration, and they stay higher above the bottom than the males. At stage V of maturity of the gonads these differences become obliterated.

The research of several authors has revealed the existence of two basic periods of oogenesis.

In the first period, the synthesizing systems in the oocytes are formed: an intensive synthesis of nucleic acids, proteins, and phosphoproteins takes place in them (2; 5). The cod are at stage II and III of maturity and they feed intensively. At the end of this stage, the initial fecundity is formed (1).

In the second period, there takes place a rapid increase in the mass of oocytes at the expense of a transfer of plastic and energy-producing

substances from other organs; there is an abrupt drop in the content of lipids in the liver and of proteins in the muscles, more readily obserable in the females than in the males. The processes of synthesis in the oocytes slow down immediately. Corresponding to these physiological characteristics, the fish also begin to feed with less intensity.

Experiments conducted for the purpose of ascertaining the impact of feeding on the intensity of generative processes show that a high level food ration results in an increased weight of the gonads and eggs and a shorter period of maturation of sexual products (11; 13). It may be of interest in this connection to consider the rate of maturation of sexual products in Baltic cod in individual years which differed with regard to food supply during the growing period preceding spawning. Females with ovaries at stage III of gonad maturity appear in the catch in late fall, although in insignificant numbers. It is only in January that the number of females with initiated oogenesis shows a marked increase. A comparison of the number of females and males with gonads at stage III of maturity in the winter period shows that the rate of maturation of sexual products differs significantly in individual years (Tab. 8), but a high index of fullness during the period preceding spawning is not a necessary condition of early maturation.

Table 8

Distribution of cod after maturity stages of the gonads (%) in January during the years with differing food supply in the preceding autumn

Degree of fullness	Years	Sex and stage of gonad maturity					
		females			males		
		II	III	IV	II	III	IV
Good	1974	85	12	3	82	18	-
	1977	64	36	-	29	61	10
	1978	89	7	4	82	15	3
Poor	1975	70	29	1	47	52	1
	1976	53	46	1	43	57	-

An analysis of the physiological condition of prospawning females of a modal size group (4 years of age) showed no significant differences during the years covered by the study (Tab. 9). The main differences were found in the reserve of plastic and energy-producing substances in the ovaries and their mass. Taking into account the specificity of protein and lipid metabolism in various tissues during oogenesis, we tried to compute the reproductivity of the effort (energy expenditure for generative processes). The computation took into account the changes in the content of lipids in the liver and proteins in the muscles at the transition from stage III of ovary maturity to stage IV, as well as the change in the content of lipids and proteins in the ovaries during the maturation of the oocytes. Calculations have shown that in 1976 the expenditure of the organism's lipids during this period amounted to 42% of the initial amount. The food of the sexually mature cod in that year contained a small amount of the most valuable component, viz. fish, and the females were exhausted. In 1975 and 1977, the expenditure of lipids was 22 and 12% respectively.

Table 9

The physiological condition of prospawning females of cod (1974-1978)

Indexes	1974	1975	1976	1977	1976
Hepatosomatic index, %	8.2	7.9	9.8	9.1	10.1
Lipid content in liver, mg/g	489	466	375	435	450
Reserve of lipids in organism, g/kg of weight	41	38	37	46	48
Protein content in muscles, mg/g	153	138	109	146	151
Lipid content in gonads, mg/g	23	19	17	16	14
Protein content in gonads, mg/g	171	143	143	139	149
Relative weight of gonads, %	16.4	16.0	20.8	19.3	17.7

The increment in energy in the ovaries during these years was the following: in 1975 - 79, in 1976 - 119 and in 1977 - 129 large calories. It must be noted that the above calculations are of preliminary nature and future research must focus on collecting data on the dynamics of the physiological processes in the organism and on establishing energy-expenditure records for various periods of the life cycle of fish in connection with various environmental factors.

Conclusion

Cod's preparation for spawning may be divided into two stages: autumn-winter and spring.

In the autumn-winter period, there is intensive feeding and establishing a reserve of plastic and energy-producing substances. The intensity of assimilatory processes is associated with the period when the food organisms for cod are the most valuable as nutritive matter. The cod's food supply during the period of growth changes with the years, and this affects the accumulation of fat and the processes of growth. An objective evaluation of the food supply, in addition to the indexes of fullness and the composition of food, requires the use of a complex of physiological and biochemical indexes.

The characteristics of cod's distribution at various depths, the possibility of isolating within one generation of specimens with initiated generative processes during the winter period allow us to conclude that toward the end of the growth period, depending on the food supply, to some extent also are determined the composition and the size of the spawning stock.

During the spring period, the food supply affects the intensity of generative processes and the enery expenditure for the formation of sexual products.

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